

GeoFun: Development of a 2D Game-based Learning Mobile Application of Geometric Shapes for Primary School Students

Wong Shiao Xuan¹, Mohd Farhan Md. Fudzee^{1*}

¹ *Fakulti Sains Komputer dan Teknologi Maklumat,*

Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author: farhan@uthm.edu.my

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Abstract

In Malaysia, geometry is a crucial mathematics topic in primary school, forming the foundation for 40% of the secondary school syllabus. In 2022, it was reported that Malaysian students' performance in the geometry domain consistently fell below the international average in the Trends in International Mathematics and Science Study (TIMSS). To address this, a 2D game-based learning mobile application named GeoFun was developed to strengthen Year 3 primary school students' understanding of geometry before progressing to more advanced levels of learning. The application was developed using the Multimedia Mobile Content Development (MMCD) methodology and includes six mini game modules and a reward system to boost engagement. Both functional and user acceptance testing was conducted, with GeoFun achieving an average System Usability Scale (SUS) score of 71.16%, indicating positive user acceptance. In conclusion, GeoFun proves to be a supplementary tool for strengthening foundational geometry skills in young learners through game-based learning.

1. Introduction

In any school curriculum, geometry is an essential topic to be taught in mathematics subject that needs students to be mastered on it. Students need to be proficient in geometry in defining geometric shapes, evaluate their properties, and compare different kinds of geometric shapes. The advantages of learning geometry include aid in the development of analytical reasoning, deductive reasoning, logical thinking, and problem-solving abilities [1].

According to the study conducted by [2], the role of teachers in utilizing technology as a teaching tool is crucial. Nevertheless, the learning resources utilized are less appealing. There is an idea that teachers use PowerPoint presentations or textbook media only to transfer geometry content from printed books to LCD media for teaching. Learning materials that are monotonous or less attractive make the process seem dull. Moreover, a study by [3] highlighted students' weaknesses in learning geometry from the teachers' perspective. These include difficulties in identifying 2D and 3D shapes, understanding the characteristics of 3D shapes, grasping basic 3D shape concepts, and recognizing 3D net shapes. The study also gathered student opinions, revealing that 167 out of 220 respondents, more than half struggled to understand geometry topics. Given these challenges in teaching and learning geometry, ranging from unengaging resources to students' difficulties in grasping basic concepts, there is a need for more innovative and interactive approaches to improve understanding and engagement.

In this modern era of technology, there are diverse game-based learning mobile applications available on any platforms such Google Play Store and App Store. Learning through games is one of the earliest and most

effective pedagogical concepts that have been used throughout human history [4]. The use of video games and components associated with game reality, content, subject, and graphics in the educational process is currently referred to as "game-based learning". However, fewer existing mobile applications focus on geometry topics for primary school students to strengthen their knowledge of geometry topics. Therefore, this project aims to design a game-based learning mobile application that is visually appealing and easy for primary school students to navigate, develop mini games in GeoFun that facilitate basic knowledge of 2D and 3D geometric shapes on the Android platform, and evaluate the functionality and user acceptance test of the GeoFun application through testing and user feedback. This application is designed for Year 3 primary school students and focuses on the "Shape and Space" topics outlined in the Year 1 to Year 3 primary mathematics textbooks under the Kurikulum Standard Sekolah Rendah (KSSR). It helps students revise both previously learned and current syllabus content by exploring basic concepts of 2D and 3D shapes, such as the properties of each shape, axis symmetry of 2D shapes and 3D shape nets. The application uses English as the language of instruction. It consists of six modules, equally divided between 2D and 3D geometry topics. Additionally, the application features a reward system where users collect star points by completing those mini games.

The rest of the paper is arranged as follows: Section 2 covers the domain of study, the technology used, and the result of the comparative analysis. Section 3 describes the MMCD methodology that has been chosen to be used in this project, as well as the output of the analysis and design phases of this project. Furthermore, Section 4 discusses the result and discussion, while Section 5 states the conclusion of this project.

2. Related Work

This section discusses the background of the study, the technology used, and the result of the comparative analysis.

2.1 Geometry Topic in Primary School Malaysia

Malaysian primary school learning standards has highlighted the importance of foundational knowledge in geometry, which includes recognizing, naming, and identifying the characteristics of 2D and 3D shapes, comparing them, arranging shapes based on patterns, identifying nets of 3D shapes, drawing basic 2D shapes, and solving practical problems involving these concepts [3]. Currently, most primary school teachers continue to use traditional methods to teach geometry, where students sit passively in the classroom while the teacher does most of the talking. In such a setting, students are often limited to copying what is written on the board, lacking opportunities to process information through critical thinking, evaluation, and analysis [5]. This limited intellectual engagement can lead to a loss of interest in learning geometry. According to research conducted by [6], not only do students lack interest in learning geometry, but some teachers also feel that the curriculum's time allocation for teaching geometry is insufficient. As a result, teachers may struggle to provide enough practice and may sometimes skip the geometry section altogether, leaving students with fewer opportunities to practice geometry questions.

2.2 Game-based Learning

Game-based learning involves using games with a serious purpose such as educational to serve as a tool for enhancing the educational process significantly. Recent studies have shown that when game elements are properly integrated into teaching, game-based learning is highly effective because of this approach is crucial in boosting students' motivation, making them feel happier, more enthusiastic, challenged, and fostering teamwork among peers [7]. Incorporating games into geometry activities can make abstract concepts more tangible for students and aid their understanding. The importance of games in geometry is heightened because the topics, shapes and objects in geometry are more abstract and require more visualization compared to other mathematical concepts [8]. However, there are some common limitations of game-based learning approach. [9] indicates that one of the issues is that not all games are designed with educational accuracy or alignment to curriculum objectives, which can reduce their effectiveness in reinforcing targeted learning outcomes. Furthermore, implementing these tools in classrooms requires thoughtful integration to avoid distractions as students might focus more on gameplay rather than learning content. Moreover, teachers may lack adequate resources or training to properly incorporate game-based tools and hence limiting their potential in educational settings. CyberChase Shape Quest [10] and DragonBox Geometry [11] are examples of game-based learning applications to learn about geometry concepts.

2.3 Educational Game

Educational games offer numerous benefits, including stimulating learning motivation and interest by creating engaging contexts that capture students' attention, improving learning outcomes by fostering a highly interactive environment where students can trial and error, and promoting the transformation of traditional

learning methods [12]. When educational games are effectively planned and executed, they can make learning both enjoyable and simple while also cultivating the development of students' affective, cognitive, psychomotor, and social skills [13]. Draw 3D Junior [14] and Shapes 3D [15] are the examples of educational game in helping students learn the basic geometry knowledge. However, there is a concern raised by [16] regarding the development of nursing video games and simulations emphasize the significance of ensuring high design and content quality in educational games. Poorly designed games or those that do not align with the curriculum can lead to student disengagement or confusion. To create content that is both engaging and relevant, careful planning and curriculum alignment are necessary, which can be resource-intensive and often require collaboration with subject matter experts. This concept should be applied to the application to make sure that the content delivered through the application aligns with the Year 1 to Year 3 primary mathematics textbooks introduced by KSSR.

2.4 Comparative Analysis

Comparative analyses were conducted on three relevant existing applications to the GeoFun application. The three applications are Shapes [17], Kids Learn Shapes [18] and Learn Shapes – Kids Games [19]. The comparison is based on 13 different features of the application. Table 1 shows the result of the comparative analysis.

Table 1 Application Comparison

| Features / Applications | Shapes | Kids Learn Shapes | Learn Shapes – Kids Games | GeoFun |
|--------------------------------|--|--|---|---|
| Operating system | Android 5.1 or above. | Android 6.0 or above. | Android 5.1 or above. | Android 5.0 or above. |
| Pricing | Free, but contains in-app purchase. | Free. | Free. | Free. |
| Application version | Full. | Lite. | Full. | Full. |
| Content focus | 2D shape. | 2D shape. | 2D shape. | 2D and 3D shape. |
| List of modules | 4 game modules: - color matching. - size matching. - shape and color matching. (The other is paid module.) | 1 learning module: Examples of real-life objects of the shape. 1 game module: Object shape recognition. | 5 game modules (Exclude color learning modules): - Object shape recognition. - Shape space recognition. - Shape pattern arrangement. - Shape recognition. | 2D geometry: - Learn characteristics of 2D shape. - Learn examples of real-life objects of 2D shape. - Learn the symmetry of axes 2D shapes. 3D geometry: - Learn characteristics of 3D shape. - Learn 3D shape nets. - Learn examples of real-life objects of 3D shape. |
| Game instructions / guidelines | None. | Provided. | Provided. | Provided. |
| Reward feature | None. | Included. | Included. | Included. |
| Local data storage | None. | None. | Included. | Included. |
| Game feature restrictions | None. | None. | Points needed to unlock more stages. | -Time limits. -Life deduction. -Perfect score required. |

Table 1: (cont)

| | | | | |
|----------------|---|---|--|--|
| Game mechanism | Drag-and-Drop. | - Sliding. - Tap. | - Drag-and-Drop. - Tap. | - Drag-and-Drop. - Tap. - Side Scrolling. |
| Strength | Relate the shape with size and color to provide other contexts beyond geometry. | Clear read-aloud explanations are provided in each of the module. | Various mini games provided in the application and context of color also covered in the application. | Allows multiple users to play using the same device. |
| Limitation | Less related to real-life objects. | Limited game modules provided in the application. | Lack of an exit confirmation prompt leads to unintended closures. | Limited rewards are provided to motivate users. |

According to Table 1, the similarities and differences between existing mobile applications and the application can be observed across distinct aspects. While the current applications focus solely on 2D shapes, the GeoFun application will include both 2D and 3D shapes, aligning with the primary year 1 to 3 primary school curriculum. This broader scope aims to deepen students' understanding of geometry by covering foundational concepts they encounter in their studies. To avoid confusion, the GeoFun application will give clear game instruction for each game module. Other than that, GeoFun includes moderately designed feature restrictions, such as time limits and life deductions to enhance engagement without creating frustration. These restrictions are intended to balance challenge with accessibility, creating an enjoyable yet educational experience. In addition, GeoFun also introduces a reward feature to motivate users. This system allows users to earn points that unlock rewards, fostering a sense of achievement and incentivizing progress through each mini game. By analyzing the strengths and limitations of each compared application, this table serves as a valuable reference for further developing GeoFun by highlighting successful features and identifying potential areas for improvement.

3. Methodology

GeoFun application has been developed using the Multimedia Mobile Content Development (MMCD) methodology [20] as depicted in Figure 1. This methodology is suitable for developing the GeoFun application because it integrates diverse multimedia elements, such as images, animations, audio, and interactive components, to create an active and effective learning environment. Furthermore, MMCD helps in optimizing mobile processing and data usage [21]. MMCD considers the limitations of mobile devices, including screen size, processing power, and memory, ensuring that the multimedia content in GeoFun application is optimized to avoid excessive resource consumption. The five phases of this methodology are the application idea creation, structure analysis, process design, main function development and testing.

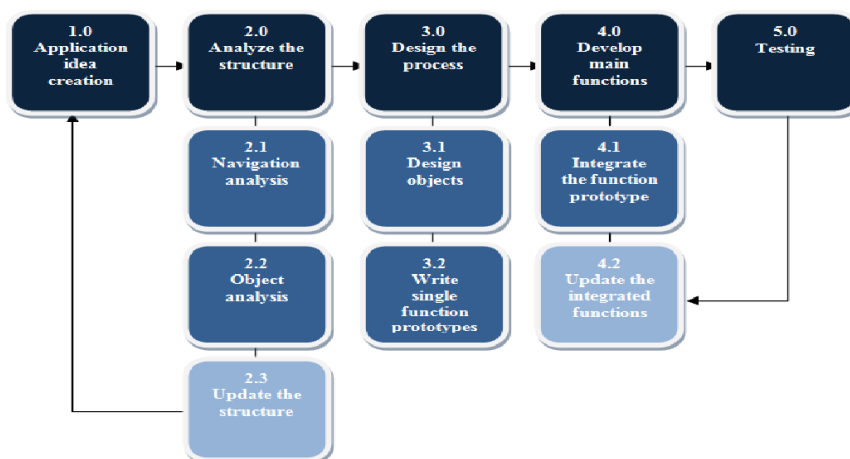


Fig. 1 MMCD Methodology [20]

3.1 Application Idea Creation Stage

In this first stage, the initial requirements needed for the development of the GeoFun application were determined. This stage involved reviewing existing applications and distributing questionnaire to the Subject Matter Expert (SME), Mr. Chan Choo Lian, who is currently teaching Mathematics at Sekolah Jenis Kebangsaan Cina (SJKC) Saleng in Kulai, Johor through online using Google Form. As a result, an application idea creation checklist has been created, as shown in Table 2. Meanwhile, Table 3 shows the user analysis extracted from the questionnaire.

Table 2 Application Idea Creation Checklist

| Item | Note |
|------------------------------|---|
| Type of application | Game-based mobile learning |
| Target device | Android smartphone and tablet |
| Target users | Year 3 primary school students |
| FPS and application settings | <ul style="list-style-type: none"> • Unity version: 2022.3.29f1 • Visual Studio Code version (C# script): 1.95.3 (user setup) • Resolution: 2400 x 1080px • FPS: 24 |
| Graphical user interface | <ul style="list-style-type: none"> • Main interface • Menu interface • Gameplay interface • Reward system interface |
| Image | <ul style="list-style-type: none"> • Background images • Button icons • Image for 2D and 3D shape objects • Images for other additional elements |
| Animation | <ul style="list-style-type: none"> • Start page animation • Reward unlocking animation |
| Video | None |
| Audio | <ul style="list-style-type: none"> • Background music • Sound effects |
| Application synopsis | GeoFun is a 2D game-based mobile learning application where the users can learn the basic knowledge on 2D, and 3D shape through a variety of mini games. In this application, there are six game modules provided for each 2D and 3D shape topic and including a reward system. |

Table 3 User Requirement Analysis

| Stakeholder category | Role in application | Design implication | Action needed |
|--|---------------------|--|---|
| Subject Matter Expert – Mr. Chan Choo Lian | Mathematics teacher | Clear instruction for the game activities | <ul style="list-style-type: none"> • Make sure the instructions are given to students before any game activities. • Make sure the instructions should be easy to understand for primary students. |
| | | Reliable content | <ul style="list-style-type: none"> • Make sure all the shapes used in the application are included in Year 1 to 3 Mathematics curriculum. |
| | | Easy to navigate | <ul style="list-style-type: none"> • Make sure students know what actions they should take to proceed to what they want. • Avoid using buttons that will mislead students' action. |
| | | Simple but colorful user interface to attract students' interest | <ul style="list-style-type: none"> • Make sure the color used is colorful but not too over. • Avoiding the color used is too monotonous. |

3.2 Structure Analysis Stage

The structure of the application to be created was studied in the second stage of the MMCD method. The navigation and object analysis were performed. Firstly, the content structure checklist was created as shown in Table 4. The navigation structure and the content structure can be found in Appendix A and B. In this phase, the functional and non-functional requirements for the application were also determined. Both are shown in Table 5 and 6 respectively. Moreover, hardware and software requirement for both users and developer are shown in Table 7 and 8 respectively. The application flowchart can be found in Appendix C.

Table 4 Content Structure Checklist of GeoFun

| Item | Note |
|---------------------|--|
| Layer design | Layer 3: C# Scripting in Unity Layer 2: Content Layer 1: Background images |
| Scene design | Frame 1: Homepage interface Frame 2: Main menu module selection Frame 3: Volume setting interface Frame 4: Gameplay interface Frame 5: Reward system interface Frame 6: Exit confirmation interface |
| Menu and navigation | <ul style="list-style-type: none"> • Start button • Exit button • Back button • Volume setting button • Game module button • Reward system button • Content buttons • Close button |
| Number of main GUI | <ul style="list-style-type: none"> • Homepage interface • Main menu interface • Reward system interface • Gameplay interfaces |

Table 5 Functional Requirements of GeoFun

| Functional requirements | Module | Description |
|-------------------------|---|--|
| User interaction | Main interface | <ul style="list-style-type: none"> • The application shall provide users with the ability to start the application. • The application shall provide users with the ability to stay or exit the application. |
| | Main menu | <ul style="list-style-type: none"> • The application shall provide users with the ability to select the modules. • The application shall provide users with the ability to go back to the initial interface. • The application shall provide users with the ability to open the volume setting panel. |
| | Volume setting panel | <ul style="list-style-type: none"> • The application shall provide users with the ability to control the volume of background music and sound effects. • The application shall provide users with the ability to close the volume setting panel. |
| | 2D geometry module (including all mini games) | <ul style="list-style-type: none"> • The application shall provide users with the ability to select the game modules. • The application shall provide users with the ability to drag-and-drop objects to certain specific areas. • The application shall provide users with the ability to tap on the objects and buttons. • The application shall provide users with the ability to pause the gameplay. |

Table 5: (cont)

| | | |
|----------------------------|---|---|
| | 3D geometry module (including all mini games) | <ul style="list-style-type: none"> • The application shall provide users with the ability to select the game modules. • The application shall provide users with the ability to tap on the objects and buttons. • The application should provide users with the ability to pause the gameplay. |
| | Reward module | <ul style="list-style-type: none"> • The application shall provide users with the ability to consume the star points for unlocking the reward. |
| Autonomous system activity | 2D geometry module (including all mini games) | <ul style="list-style-type: none"> • The application shall be able to store the star points that the user obtained once they completed each mini game. • The application should display immediate feedback on whether the answer was correct or incorrect. • The application will display a pop-up window automatically on the user screen if the time is up. • The application shall randomize the questions for each time the users play. |
| | 3D geometry module (including all mini games) | <ul style="list-style-type: none"> • The application should be able to store the star points that the user obtained once they completed each mini game. • The application shall display immediate feedback on whether the answer was correct or incorrect. • The application should deduct the lives automatically when the users answer incorrectly. • The application shall randomize the questions for each time the users play. |
| | Reward module | <ul style="list-style-type: none"> • The application will deduct star points automatically after users choose to spend stars to unlock the reward. |

Table 6 Non-functional Requirements of GeoFun

| Non-Functional Requirement | Description |
|----------------------------------|---|
| Performance | <ul style="list-style-type: none"> • Any interaction between the users and the application should not exceed 10 seconds. • The application should be available for use 24 hours per day, 365 days per year. |
| Operational | <ul style="list-style-type: none"> • The application will run on Android mobile devices. • The application should be compatible with Android 5.0 or above. |
| Ease of use | <ul style="list-style-type: none"> • The application should provide enough instructions and easy to navigate. |
| Cultural | <ul style="list-style-type: none"> • The application shall be developed in English only. |
| Graphical user interface support | <ul style="list-style-type: none"> • The application should support all multimedia elements such as images, animations, audio, and text for different sizes of display resolution on Android mobile. |
| Availability | <ul style="list-style-type: none"> • The application and its data should be able accessed without the internet. |

Table 7 Hardware and Software Requirements for Users

| Requirement | Item | Description |
|-------------|------------------------|---|
| Hardware | Android mobile devices | Allow the user to access the developed application. Specifications are as follows: <ul style="list-style-type: none"> • Processor: Quad-core processor or higher • Installed Memory (RAM): Equal or more than 4.0 GB • Storage: Equal or more than 64 GB • Internet connectivity: Reliable internet connectivity for downloading the application. |
| Software | Operating system | Android OS version 5.0 or higher. |
| | Browser | Allow the user to download the application through the web browser. |

Table 8 Hardware and Software Requirements for Developer

| Requirement | Item | Description |
|-------------|----------------------------|--|
| Hardware | Laptop Acer Nitro AN515-57 | Allow the developer to use Unity and Adobe Illustrator to develop the application. Specifications as follows: <ul style="list-style-type: none"> • Operating System: Window 11 • Processor: 11th Gen Intel(R) Core (TM) i5-11400H • Memory Installed (RAM): 8.00 GB • Storage: 475 GB • Graphics: NVIDIA® GeForce RTX™ 3060 |
| | Vivo V17 | Allow the developer to run and test the application Specifications as follows: <ul style="list-style-type: none"> • Operating System: Android 12.0 • Resolution: 1080 x 2400 • RAM: 8.00 GB • Internal storage: 256 GB • CPU: 2.0 GHz Snapdragon 657 Octa-core |
| | Input-output devices | Allow the developers to communicate with the computer using: <ul style="list-style-type: none"> • Mouse / Touchpad • Keyboard |
| Software | Unity 2022.3.29f1 | Provide the developer a platform to design and build the application. |
| | Visual Studio Code 2022 | Used to write Unity C# scripts for the application. |
| | Adobe Illustrator 2020 | Used to design the buttons. |
| | Canva | Used to design the assets such as 2D graphics and background images. |
| | Draw.io | Used to create the application flowchart, navigation structure and content structure of the application. |
| | Y2Mate | Used to download audio by converting YouTube videos which free from copyright to MP3 format. |

3.3 Process Design Stage

The activities involved in this third stage of MMCD methodology are object design and single function prototype scripting. In this project, the objects required by the application include navigation buttons and high-fidelity storyboard. Authoring tools such as Canva and Adobe Illustrator are utilized to design the buttons and user interfaces while Unity is used to develop and integrate all the components needed for the scripting process. Table 9 and 10 present the button designs and the interface design of the GeoFun application. The single function prototype can be referred to Appendix D.

Table 9 Button design















| Button | Description | Button | Description | Button | Description |
|--|--|--|--|--|---|
|  | This is the start button. |  | This is a resume button. |  | This is a retry button. |
|  | This is an answer submit button. |  | This is a user record deletion button. |  | This is a user record button. |
|   | Buttons to confirm or cancel the user deletion task. |   | These are the button to open the mini game menu for each category. |   | Buttons to confirm or cancel the user record creation task. |
|  | This is an exit button. |  | This is a button to proceed to next level. |  | This is a done to proceed next scene. |

Table 9: (cont)





















| | | | | | |
|---|---|---|--|---|--|
|  | This is a star deducted button. |  | This is a user record creation button. |  | Example button to start each mini game. |
|  | This is a close panel button. |  | This is a back button. |  | This is a volume setting button. |
|  | This is a pause button |  | This is an exit button. |  | This is a reset input button. |
|  | This is a help button. |  | This is an exit confirmation button. |  | This is a game credit button. |
|  | This is a more button. |  | This is a back to home button. |  | This is a tooltips button. |
|  | This is a button to open reward collection panel. |  | These are the left and right movement buttons. |  | This is a button to open the reward interface. |
|  | This is a play again button. |  | This is a jump button. | | |

Table 10 Interface design





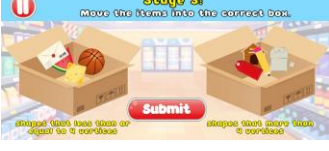



| Interface | Description | Interface | Description |
|---|--|--|---|
|  | This is the startup interface of the application. It consists of Start, Exit, More, Credits, and Tooltips buttons, where users can choose any of them. |  | This is the panel where users can create, delete, or select a user record to play. |
|  | This is the main menu where users can choose to proceed to either the 2D or 3D geometry mini games menu. |  | This is an example of the mini game menu. Users can freely choose any of the mini games. |
|  | This is an example of the gameplay interface for the 'Sort Me' module. Users need to drag and drop the objects into boxes and submit their answers. |  | This is an example of the gameplay interface for the 'Find Me' module. Users need to tap on the correct objects as specified in the question. |
|  | This is an example of the gameplay interface for the 'Pair Me' module. Users need to tap on two cards to match them and form symmetrical shapes. |  | This is an example of the gameplay interface for the 'Count Me' module. Users need to enter their answer using the on-screen calculator. |

Table 10: (cont)

| | | | |
|--|---|--|--|
| | <p>This is an example of the gameplay interface for the 'Guess Me' module. Users need to tap on the correct answer.</p> | | <p>This is an example of the gameplay interface for the 'Collect Me' module. Users need to control the character to collect the items.</p> |
| | <p>This is the interface where users can unlock rewards using the star points they have collected.</p> | | <p>This is the interface that displays all the unlocked rewards.</p> |

3.4 Main Function Development Stage

This stage focuses on developing the GeoFun application using Unity. It is crucial to transform the concept into a fully operational application by integrating and refining the functional prototypes into complete features. The development process includes creating assets and integrating into Unity with scripting. Table 11 shows the development of application assets, which includes preparing graphics, audio, and animations to be integrated into the application. Subsequently, C# scripting is applied to ensure that each mini game implements the correct game logic and functions as intended. The local database implementation and key functions of each mini game are presented in Table 12.

Table 11 Development of assets

| Assets | Development | Description |
|----------|-------------|---|
| Graphics | | <p>All the navigation buttons were created using Adobe Illustrator. The buttons were then exported as PNG files and uploaded to Canva for integration with the icons. Additionally, some other graphics in the application, such as the rewards, were also created using the same software.</p> <p>In Canva, the buttons are edited by adding text or icons to clearly represent their functions.</p> |
| Audio | | <p>All the audio files were downloaded from free online platforms such as Pixabay and YouTube, which offer royalty-free content. The videos were then converted to MP3 format using online converter tools.</p> |

Table 11: (cont)

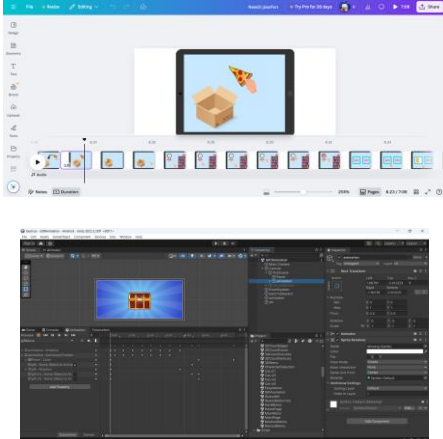
| | | |
|-----------|---|--|
| Animation |  | <p>Canva and Unity are primarily used to create 2D animations for integration into the application. Canva is used to create animations such as the landing page for the application and the quick tutorials for the mini games. In contrast, Unity is used to create button animations, character movements in the "Collect Me" module, and reward unlocking animations. Some 2D animations or GIFs are also sourced from online resources such as LottieFiles and Canva assets.</p> |
|-----------|---|--|

Table 12 C# Scripting for integration in Unity

| Functions | Code segment | Description |
|--|---|---|
| Delete user record | <pre>public static void DeleteProfile(string userName) { string path = Path.Combine(profileDirectory, \$"{userName}.json"); if (File.Exists(path)) File.Delete(path); }</pre> | <p>This method deletes a saved user profile. It builds the file path based on the provided username and checks if the corresponding .json file exists. If it does, the method deletes the file from the disk.</p> |
| Save user record | <pre>public static void SaveProfile(UserProfile profile) { if (!Directory.Exists(profileDirectory)) Directory.CreateDirectory(profileDirectory); string path = Path.Combine(profileDirectory, \$"{profile.userName}.json"); File.WriteAllText(path, JsonUtility.ToJson(profile, true)); }</pre> | <p>This method saves a UserProfile object as a JSON file. It first checks if a directory exists and creates it if it does not. Then, it creates a file path using the user's name and writes the JSON representation of the profile to that file using Unity's JsonUtility.ToJson method with formatting enabled.</p> |
| Handle dragged object and drop zone in Sort Me | <pre>public void OnDrop(PointerEventData eventData) { Q2SideDraggableItem item = eventData.pointerDrag.GetComponent<Q2SideDraggableItem>(); if (item != null) { itemsInZone.Add(item); item.transform.SetParent(transform); } }</pre> | <p>This method handles an object with the Q2SideDraggableItem script being dropped onto a target area by adding the dragged item to a list and setting its parent to the drop zone.</p> |
| Handle the object clicked in Find Me module | <pre>public void OnPointerClick(PointerEventData eventData) { if (!isClicked) { isClicked = true; if (isCorrectItem && correctIcon != null) { correctIcon.SetActive(true); } else if (!isCorrectItem && incorrectIcon != null) { incorrectIcon.SetActive(true); } } }</pre> | <p>This method checks whether the user has pressed the correct object and displays the corresponding icon. If the object has been pressed before, it will not be marked as "isClicked".</p> |
| Shuffle the cards in Pair Me module | <pre>private void ShuffleList(List<int> list) { for (int i = 0; i < list.Count; i++) { int randomIndex = rnd.Next(0, list.Count); int temp = list[i]; list[i] = list[randomIndex]; list[randomIndex] = temp; } }</pre> | <p>This method randomly shuffles the elements of a list by swapping each item with another at a random position, ensuring a mixed-up order.</p> |
| Update the number on screen in Count Me module | <pre>public void OnNumberButtonClick(string number) { if (playerInput.Length < 3) { playerInput += number; inputDisplay.text = playerInput; } }</pre> | <p>This method adds a number to the player's input when a number button is clicked. It then updates the displayed input accordingly.</p> |

Table 12: (cont)

| | | |
|---|---|--|
| Handle the question sequence in Guess Me module | <pre>private void ShowNextQuestion(){ if (currentQuestionIndex != -1){ questionCanvases[currentQuestionIndex].SetActive(false);} int randomIndex = Random.Range(0, remainingQuestions.Count); currentQuestionIndex = remainingQuestions[randomIndex]; remainingQuestions.RemoveAt(randomIndex); questionCanvases[currentQuestionIndex].SetActive(true); currentQuestionNumber++;}</pre> | This method handles showing the next question in a quiz or game by hiding the current question and picks a new random question from the remaining ones. It then displays and updates the question count. |
| Handle the collision between character and items in Collect Me module | <pre>private void OnTriggerEnter2D(Collider2D collision){ if (collision.CompareTag("CorrectItem")){ collectedItems++; Destroy(collision.gameObject);} if (collision.CompareTag("WrongItem")){ LoseLife(); Destroy(collision.gameObject);} if (collision.CompareTag("empty")){ SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex);}}</pre> | This method detects when the player collides with other objects. If it is a "CorrectItem," it increments the collected items count and removes the item. If it is a "WrongItem," the player loses a life and the item is destroyed. If it hits an "empty" object, the current scene will reload. |

3.5 Testing Stage

The final stage of MMCD methodology is testing where alpha and beta testing were conducted. Firstly, alpha testing was performed early in the development process within a controlled environment to identify and resolve any bugs or logic errors in the application. This test provides an opportunity to address overlooked issues or minor mistakes before moving forward. The result of functional testing as shown in Table 13.

Table 13 Functional testing

| Test | Expected Output | Actual Output | Corrective Action |
|-----------------------------------|--|------------------------|-------------------|
| Panel / confirmation window | A panel or window smoothly pops up when the button is clicked. | Work well as expected. | Not required. |
| Exit application function | The application closes completely when the exit button is pressed. | Work well as expected. | Not required. |
| Game paused | Pause panel is displayed on the screen. | Work well as expected. | Not required. |
| Scene transition | Scene transitions are smoothly handled by a script. | Work well as expected. | Not required. |
| Retry/ replay function | Each mini game can be retried after failure or replayed upon completion. | Work well as expected. | Not required. |
| Implementation of Sort Me module | Objects can be dragged to certain regions. The regions able to store the objects placed on them. User's answer will be checked with the preset answer. | Work well as expected. | Not required. |
| Implementation of Find Me module | Display the correct / wrong icon based on the user's touch input and update the timer and remaining number of items that need to be found. | Work well as expected. | Not required. |
| Implementation of Pair Me module | Users can flip two cards at a time. If the cards do not match, they will automatically flip back otherwise a tick icon will be displayed. | Work well as expected. | Not required. |
| Implementation of Count Me module | Read the user's input and compare it with the preset answers. The hint will be provided based on the criteria. | Work well as expected. | Not required. |
| Implementation of Guess Me module | Detect the user's answer and update the timer and chances based on their answer. | Work well as expected. | Not required. |

Table 13: (cont)

| | | | |
|-------------------------------------|---|---|--|
| Implementation of Collect Me module | The character able to move right, left and jump based on the user's control. The collision between the character with the items should be detected. | - Movement can be unresponsive at times, making it feel unnatural. - Oversized colliders cause the character to collide despite some space from obstacles. | - Adjust colliders on all elements and update the script. - Adjust the colliders on all elements to the appropriate size. |
| Implementation of reward system | Deduct the star point used and unlock the rewards randomly without repetition. | Work well as expected. | Not required. |
| Implementation of local database | Able to store, delete, retrieve and display the user record in the application. | Work well as expected. | Not required. |
| Implementation of audio | The volume of background music and sound effects are adjusted and played when necessary. | Work well as expected. | Not required. |

Subsequently, beta testing was conducted in a real-world setting which involved the target users of the application. The students were invited to interact with the application, and after the testing session, a questionnaire was distributed to gather their feedback on their satisfaction and overall experience with the application. The questionnaire utilizes the System Usability Scale (SUS) [22]. The results of the beta testing will be discussed in the next section.

4. Results and Discussion

The user acceptance test was conducted at Sekolah Jenis Kebangsaan (Cina) Kong Nan, Parit Raja, Johor, involving a total of 28 Year 3 primary school students. SUS-based questionnaire was distributed to the students after they used the application. The results for each question are visualized in Figures 2(a) and 2(b).

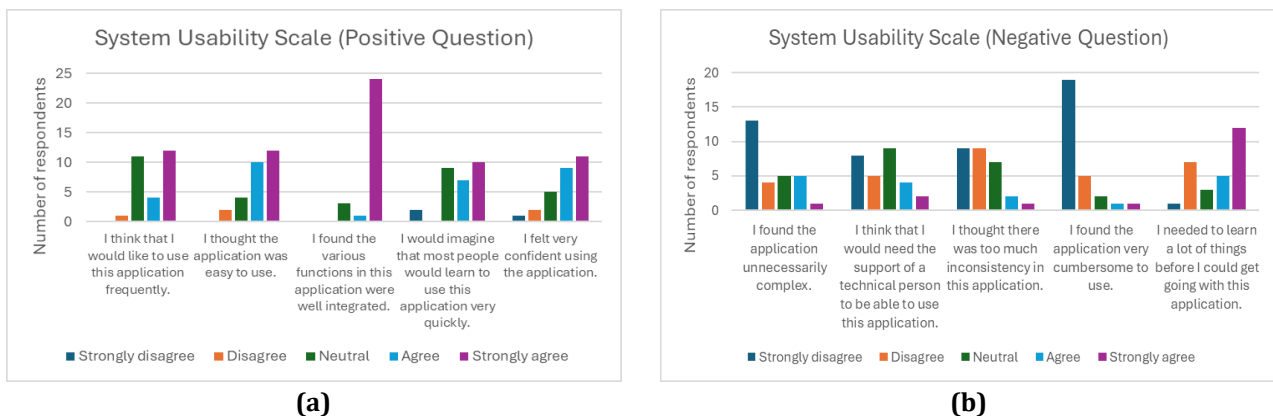


Fig. 2 (a) SUS positive question result; (b) SUS negative question result

Based on Figure 2(a), most responses to the positive questions tended to fall within the “neutral”, “agree”, and “strongly agree” categories. This indicates that over 80.00% of users generally agreed that they would like to use the application frequently, found it easy to use, believed it was well-integrated with various functions, experienced a short learning curve, and felt confident using it. Notably, 85.71% of users strongly agreed with the statement, “I found the various functions in this application were well integrated.”, indicating that the application’s features were accessible and responsive to their needs. Only less than 10.00% of users responded with “strongly disagree” or “disagree,” showing that the majority were satisfied with and confident using the application.

Whereas on Figure 2(b), most responses to the negative questions tended to fall within the “strongly disagree,” “disagree,” and “neutral” categories. For example, nearly 67.86% of users strongly disagreed the statement “I found the application very cumbersome to use”, indicating that users found the application easy to use and did not require too many steps to complete an action. However, 64.29% of users strongly agree with the statement, “I needed to learn a lot of things before I could get going with this application.”. This result may be attributed to the application being developed in English, whereas the students typically learn geometry topics in Chinese. As a result, they may have needed to understand specific geometry-related English terminology before they could comfortably use the application.

Table 14 Respondent score for the SUS

| Respondent | Item score | | | | | | | | | | Odd score | Even score | Total Score |
|----------------------|------------|----|----|----|----|----|----|----|----|-----|-----------|--------------|-------------|
| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | | | |
| R01 | 5 | 1 | 5 | 5 | 5 | 2 | 4 | 1 | 4 | 4 | 18 | 12 | 75.00 |
| R02 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 5 | 5 | 16 | 14 | 75.00 |
| R03 | 3 | 1 | 4 | 2 | 3 | 2 | 4 | 1 | 5 | 5 | 14 | 14 | 70.00 |
| R04 | 3 | 4 | 5 | 3 | 5 | 2 | 3 | 1 | 4 | 5 | 15 | 10 | 62.50 |
| R05 | 4 | 3 | 5 | 3 | 5 | 2 | 5 | 2 | 3 | 4 | 17 | 11 | 70.00 |
| R06 | 3 | 1 | 3 | 2 | 5 | 4 | 4 | 2 | 3 | 5 | 13 | 11 | 60.00 |
| R07 | 3 | 1 | 4 | 3 | 5 | 1 | 3 | 1 | 3 | 5 | 13 | 14 | 67.50 |
| R08 | 3 | 2 | 4 | 5 | 5 | 3 | 1 | 2 | 4 | 5 | 12 | 8 | 50.00 |
| R09 | 3 | 4 | 3 | 3 | 5 | 1 | 3 | 1 | 2 | 4 | 11 | 12 | 57.50 |
| R10 | 3 | 2 | 5 | 3 | 5 | 2 | 3 | 1 | 4 | 2 | 15 | 15 | 75.00 |
| R11 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 3 | 5 | 5 | 20 | 5 | 62.50 |
| R12 | 5 | 3 | 4 | 4 | 5 | 3 | 3 | 2 | 4 | 5 | 16 | 8 | 60.00 |
| R13 | 5 | 5 | 5 | 1 | 5 | 5 | 5 | 1 | 5 | 5 | 20 | 8 | 70.00 |
| R14 | 3 | 2 | 4 | 2 | 3 | 2 | 4 | 1 | 2 | 3 | 11 | 15 | 65.00 |
| R15 | 3 | 2 | 5 | 1 | 5 | 1 | 3 | 1 | 1 | 4 | 12 | 16 | 70.00 |
| R16 | 4 | 1 | 5 | 4 | 5 | 3 | 5 | 1 | 4 | 2 | 18 | 14 | 80.00 |
| R17 | 5 | 1 | 3 | 1 | 5 | 1 | 5 | 1 | 3 | 2 | 16 | 19 | 87.50 |
| R18 | 5 | 1 | 5 | 3 | 4 | 3 | 4 | 1 | 4 | 2 | 17 | 15 | 80.00 |
| R19 | 5 | 1 | 5 | 1 | 5 | 3 | 5 | 1 | 5 | 1 | 20 | 18 | 95.00 |
| R20 | 2 | 1 | 2 | 4 | 5 | 1 | 4 | 4 | 4 | 2 | 12 | 13 | 62.50 |
| R21 | 4 | 3 | 4 | 3 | 5 | 2 | 5 | 1 | 5 | 3 | 18 | 13 | 77.50 |
| R22 | 5 | 3 | 4 | 1 | 5 | 3 | 5 | 2 | 5 | 5 | 19 | 11 | 75.00 |
| R23 | 5 | 4 | 4 | 3 | 5 | 2 | 5 | 3 | 5 | 4 | 19 | 9 | 70.00 |
| R24 | 4 | 1 | 5 | 3 | 5 | 1 | 3 | 1 | 5 | 3 | 17 | 16 | 82.50 |
| R25 | 5 | 3 | 4 | 1 | 5 | 1 | 3 | 1 | 5 | 5 | 17 | 14 | 77.50 |
| R26 | 5 | 1 | 5 | 2 | 5 | 1 | 3 | 1 | 3 | 5 | 16 | 15 | 77.50 |
| R27 | 5 | 4 | 2 | 1 | 5 | 3 | 1 | 5 | 4 | 2 | 12 | 10 | 55.00 |
| R28 | 3 | 1 | 3 | 1 | 3 | 1 | 5 | 1 | 5 | 2 | 14 | 19 | 82.50 |
| Average score | | | | | | | | | | | | 71.16 | |

Based on Table 14, the scores ranged from 50.00 to 95.00. The lowest score of 50.00, recorded by respondent R08, suggests that this user experienced dissatisfaction or difficulties while using the application. In contrast, the highest score of 95.00, achieved by respondent R19, indicates high satisfaction and enjoyment with the application. These statistics show that the developed application provided varying user experiences, depending on how each respondent felt after trying it.

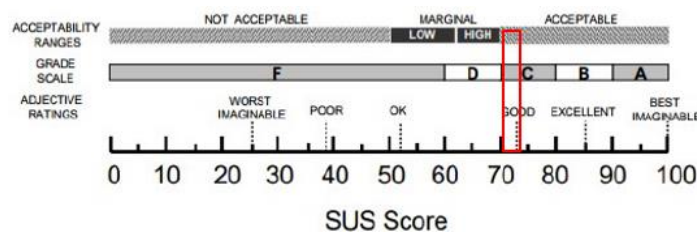


Fig. 3 Grade rankings of SUS scores [22]

The average SUS score shown in Table 14 is 71.16%, which falls within the acceptable range based on the grade ranking presented in Figure 3. This result indicates that GeoFun is generally well-received by users and meets standard usability expectations. However, the score does not fall within the "excellent" range (80–90), which may be attributed to several factors. One possible reason is that some respondents may have had difficulty understanding the geometry topics presented in English, as they are more familiar with learning the subject in Chinese. Additionally, the limited time allocated for each user to explore the application may have impacted their overall experience, as some users might not have had the chance to try all the games included.

5. Conclusion

In conclusion, GeoFun has been successfully developed to meet user requirements and the project objectives outlined during the planning phase. The application was designed to be user-friendly, visually appealing, and easy to navigate for primary school students. Moreover, it helps students strengthen their basic knowledge of geometry through the mini games provided. All mini-games and other features are well-integrated, and the positive feedback received from target users during testing indicates that the application can serve as a supportive learning tool while also providing enjoyment and engagement for students.

Building on this success, the GeoFun application offers several key contributions to primary mathematics education. It is a valuable supplementary classroom tool for teachers to reinforce students' understanding of geometry. Furthermore, the application encourages self-directed learning by allowing students to independently choose and navigate mini games, promoting autonomy and problem-solving skills. Integrating gamification elements such as rewards, levels, and challenges creates an engaging and motivating learning environment. This approach also supports sustainable, long-term learning, as students remain motivated to revisit and reinforce geometry concepts over time.

Future improvements are recommended for GeoFun to enhance its usability further. Integrating a real-time database like Firebase would enable features such as live leaderboards, boosting user engagement and motivation. It is also suggested that a multiplayer mode be added to promote collaboration, teamwork, and social interaction among users to address the current limitation of individual play. Additionally, expanding the range of geometry topics to include more advanced concepts and real-world problems would foster critical thinking and better prepare them for higher-level mathematics.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Wong Shiao Xuan, Mohd Farhan Md. Fudzee; **data collection:** Wong Shiao Xuan, Mohd Farhan Md. Fudzee; **analysis and interpretation of results:** Wong Shiao Xuan, Mohd Farhan Md. Fudzee; **draft manuscript preparation:** Wong Shiao Xuan, Mohd Farhan Md. Fudzee. All authors reviewed the results and approved the final version of the manuscript.

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Appendix A: Navigation Structure of GeoFun

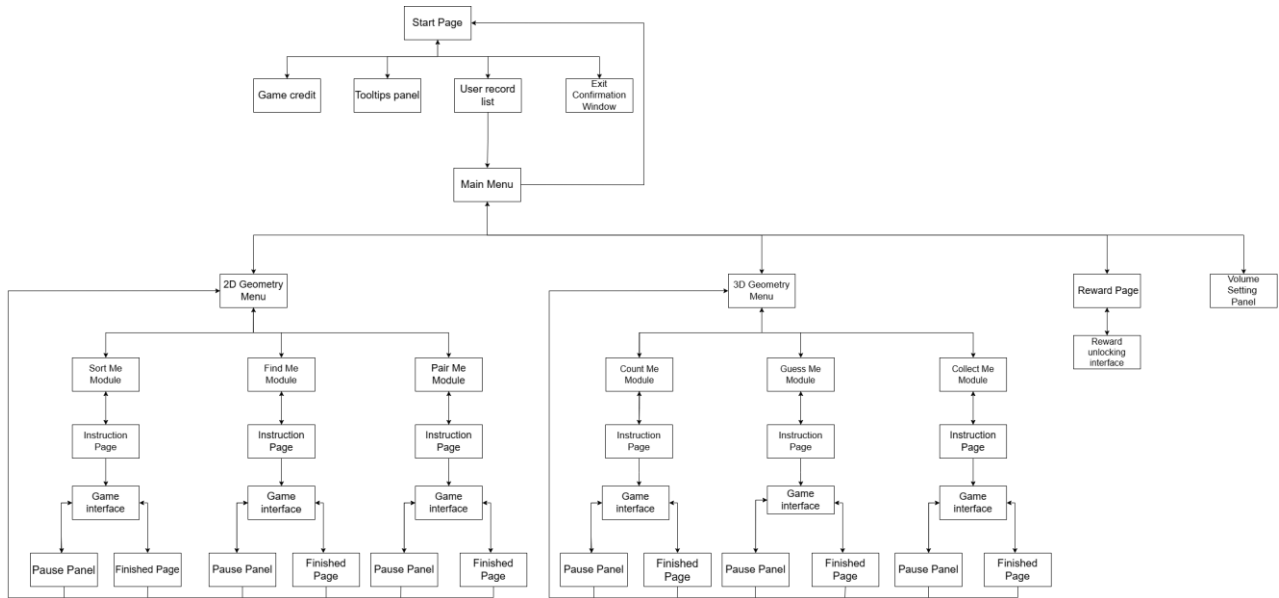


Fig. 4 Navigation Structure of GeoFun

Appendix B: Content Structure of GeoFun

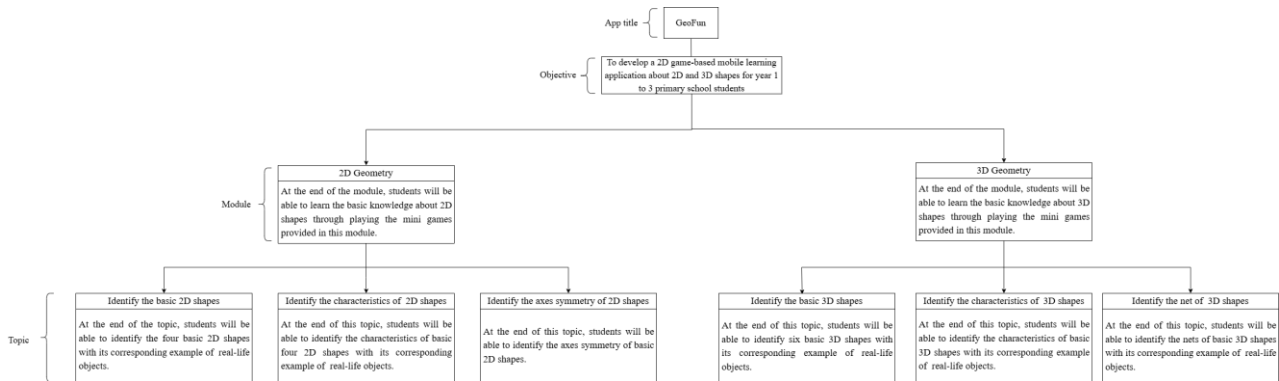


Fig. 5 Content Structure of GeoFun

Appendix C: Application Flowchart of GeoFun

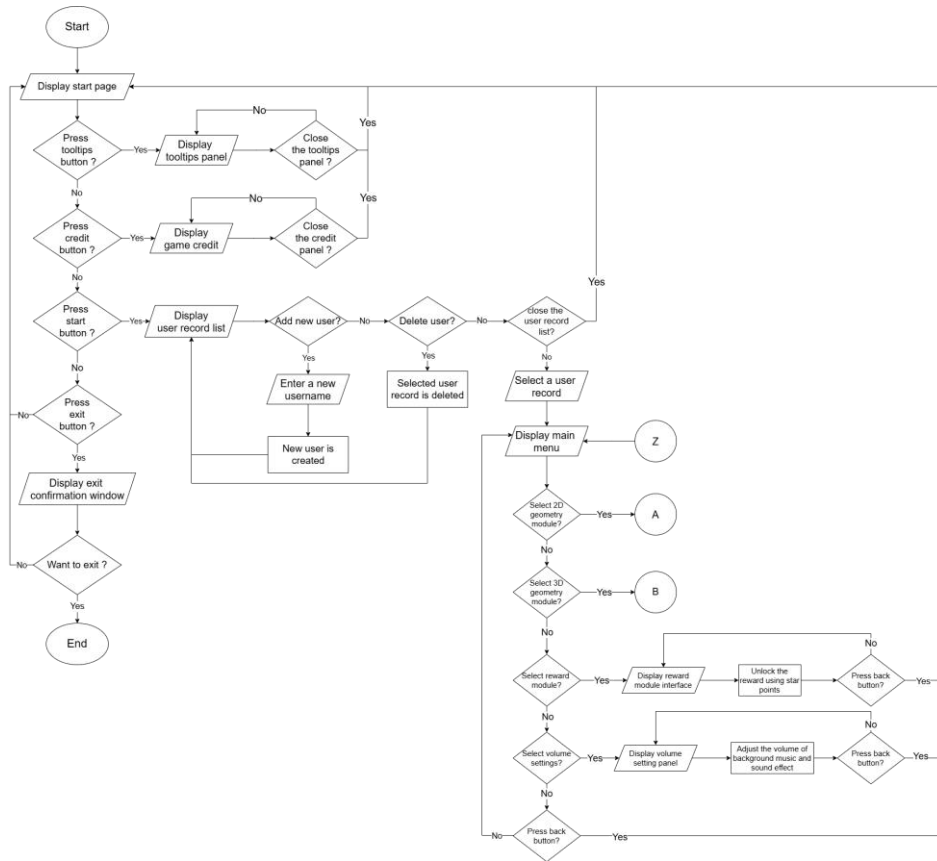


Fig. 6 Main flow of Geofun

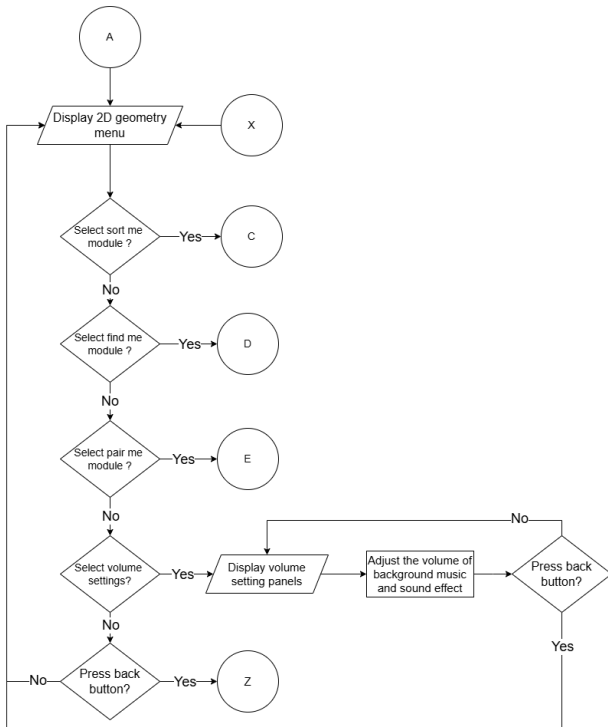


Fig. 7 Flowchart of "2D Geometry" Menu

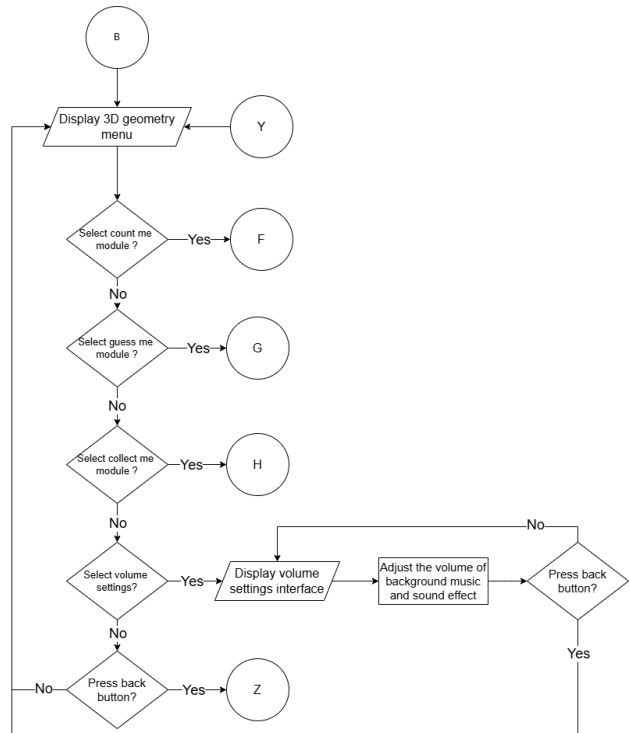


Fig. 8 Flowchart of "3D Geometry" Menu

Appendix D: Single Function Prototype

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class SceneChange : MonoBehaviour
{
    // Start is called before the first frame update
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {

    }

    public void ChangeScene() {
        SceneManager.LoadScene("MainPage");
    }
}
```

Fig 15. Code snippet for loading scene

```
using UnityEngine;
using UnityEngine.UI;

public class PopUpFunction : MonoBehaviour
{
    public GameObject popupWindow;
    public Button openWindow;
    public Button closeWindow;

    private void Start()
    {
        popupWindow.SetActive(false);
        openWindow.onClick.AddListener(OpenPopup);
        closeWindow.onClick.AddListener(ClosePopup);
    }

    private void OpenPopup()
    {
        popupWindow.SetActive(true);
    }

    private void ClosePopup()
    {
        popupWindow.SetActive(false);
    }
}
```

Fig 16. Code snippet for loading scene